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In situ Stabilization/Solidification

(U.S.) Naval Energy and Environmental Support Activity
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Abstract: Stabilization and solidification waste treatment processes involve the mixing of specialized additives or reagents with waste materials to reduce physically or chemically the solubility or mobility of contaminants in the environmental matrix. The term 'stabilization' is used to describe techniques that chemically modify the contaminant to form a less soluble, mobile, or toxic form without necessarily changing the physical characteristics of the waste. Solidification refers to a technique for changing the physical form of the waste to produce a solid structure in which the contaminant is mechanically trapped. Many stabilization and solidification processes overlap, and the common terminology to describe either or both processes is stabilization/solidification (S/S). Goals of the application of S/S techniques include improving the physical and handling characteristics of liquid or semi-liquid contaminated materials, reducing contaminant solubility, and decreasing the rate of transfer of the contaminant. It is important to emphasize that typically S/S does not provide for contaminant destruction and therefore may not be classified as a permanent solution.

In Situ Stabilization/ Solidification

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Introduction

NEESA's Remedial Action (RA) Tech Data Sheets are concise, factual, and up-to-date summaries of practical aspects of hazardous waste RA technologies. Where required for clarification, specific technical information is included.

Purpose and Audience

The Tech Data Sheets are designed to:

- Disseminate practical, implementation-related information such as performance criteria, quality control requirements, applications examples, lessons learned, and cost data to minimize the potential for design and construction problems;
- Enable Remedial Project Managers (RPMs) to evaluate technologies recommended in Feasibility Studies (FSs);
- Aid RPMs in writing an RA Delivery Order;
- Help Navy Engineering Field Division (EFD) Remedial Design personnel to write a Statement of Work (SOW) or RPMs to review remedial project design plans, and
- Enable field personnel such as Project Superintendents, Engineers in Charge, On-Scene Coordinators (OSCs), and Resident Officers in Charge of Construction (ROICCs) to become familiar with a technology at a site they will be overseeing.

Description of Technology

Stabilization and solidification waste treatment processes involve the mixing of specialized additives or reagents with waste materials to reduce physically or chemically the solubility or mobility of contaminants in the environmental matrix. The term "stabilization" is used to describe techniques that chemically modify the contaminant to form a less soluble, mobile, or toxic form without necessarily changing the physical characteristics of the waste. Solidification refers to a technique for changing the physical form of the waste to produce a solid structure in which the contaminant is mechanically trapped. Many stabilization and solidification processes overlap, and the common terminology to describe either or both processes is stabilization/solidification (S/S).

Goals of the application of S/S techniques include improving the physical and handling characteristics of liquid or semi-liquid contaminated materials, reducing contaminant solubility, and decreasing the rate of transfer of the contaminant. It is important to emphasize that typically S/S does not provide for contaminant destruction and therefore may not be classified as a permanent solution.

S/S processes have been used for the treatment of heavy metal-containing industrial waste treatment sludges prior to their ultimate disposal to minimize the potential for future leaching of the heavy metals into the environment. More recently, S/S has been evaluated as a lower cost treatment alternative for contaminated soils and sediments. It is the remedial application that is the focus of this Tech Data Sheet.

S/S systems can be used to treat contaminated soil or wastes in place (in situ) or can be employed to treat excavated wastes externally for their subsequent disposal. **This Tech Data Sheet specifically addresses practical implementation considerations relating to in situ treatment with no excavation of untreated or treated materials.**

The primary mechanisms of in situ S/S processes include (1):

- Removal of Free Liquid—involving the addition of a solid to the waste to take up any free liquid. Examples of such solids include activated carbon, sawdust, gypsum, clays, and silicates;
- Lime/Fly Ash Pozzolan Reactions—involving a reaction between non-crystalline silica in fly ash and lime to produce a low-strength solid in which contaminants are physically trapped;

- Pozzolan Cement Reactions—which employ a pozzolan such as fly ash and cement to produce a relatively high-strength waste concrete matrix in which contaminants are trapped;
- Vitrification—typically involving the addition of chemicals (silica, borax, soda ash, etc.) and the application of electrical energy to produce a solidified product.

Of these, the processes with the greatest potential effectiveness at the lowest cost are those involving the addition of lime, pozzolans, and or cement. The remainder of this Tech Data Sheet focuses on these systems.

The quality and type of additive or binder system will be selected based on waste and site characteristics as well as the desired characteristics of the treated material.

Of all the factors that impact the success of in situ S/S in the treatment of contaminated soil, the addition of the reagent and thorough and uniform mixing of the reagent and the soil are the most critical (see "Field Implementation Considerations").

Surface infiltration barriers (caps) and subsurface barriers such as slurry walls may be used in conjunction with in situ S/S (see "Interface with Other Technologies"). An illustrative example of an in situ S/S application with barrier wall and surface cap is provided in Figure 1.

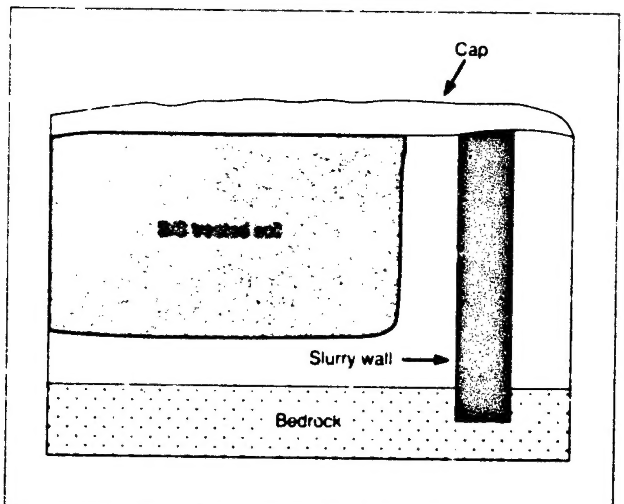

Figure 1. In Situ S/S Application (Cross Section)

Technology Status

S/S technologies have been employed in full-scale surface and in situ applications involving metal-bearing and oily wastewater treatment sludges. The application of S/S for soil and sediment treatment has been a more recent application, particularly with respect to in situ treatment, which is in its relative infancy.

Because of the more recent remedial use of S/S techniques, little is known of long-term effectiveness in terms of fate of the contaminant or integrity of the solid product.

In situ S/S has not yet been employed in remedial actions at Navy sites. Consequently, there have been no statements of work, plans and specifications, or cost estimates prepared for contracting efforts to implement the technology at Navy sites.

An in situ S/S process was selected for participation in the Demonstration Program phase of the Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) Program. This Demonstration Program is designed to develop engineering and cost data on selected technologies to provide for an assessment of technology performance, reliability, and cost. Preliminary results of this demonstration (see "Application Examples") indicate that the technology has the potential to be practically and cost effectively employed.

Contaminants Mitigated

S/S has proven most useful for the treatment of inorganic-containing waste materials including heavy metals. Its utility for the treatment of many organic wastes appears to be limited due to the potential for detrimental chemical interactions, the volatility of the organic compounds, limited success in reducing organic mobility, and competition from other available technologies.

S/S techniques have been demonstrated for use in the control of a variety of contaminants including metals (i.e., chromium, lead, aluminum, nickel), asbestos, polychlorinated biphenyls (PCBs), and radioactive and oily wastes. Specific limitations are described below.

Despite the demonstrated use of S/S techniques, there are few data available to confirm the long-term effectiveness of the technology.

As the technology develops, additives are being used in conjunction with the setting reagents to improve the binding of the contaminant to the solid product and/or to provide for the transformation of the contaminant into a less toxic or mobile form. Use of these additives may extend the S/S application to a wider range of contaminants, including many organics.

Applications, Advantages, and Limitations

In situ S/S may provide a method for the treatment of contaminated soil, which may not be economically or technically feasible to excavate. Examples of such uses include the treatment of:

- Contaminated soils under or adjacent to existing structures;
- Contaminated soils in areas of ongoing industrial activities; and
- Contaminated soils for which excavation would increase the potential for the spread of contamination to groundwater.

Other situations for which in situ S/S may be well-suited include:

- Those that allow for the addition of large amounts of bulk solid reagent(s) to ensure adequate contact between the reagent and the contaminated soil; and
- Contaminated sites with homogeneous chemical and physical characteristics.

The in situ S/S process may represent a quick-to-implement, low-cost remedial alternative. Generally, the additives (reagents or binders) for S/S applications are readily available and relatively inexpensive. In addition, there are no excavation and related material handling costs. Also, fewer associated health and safety measures are required.

Indications are that in situ S/S may provide a short-term remedial solution. Because in situ S/S is a relatively new process, data reflecting the long-term quality of the treated matrix are not available, and therefore definitive conclusions regarding long-term effectiveness cannot be drawn.

Despite the potential favorable applications of in situ S/S, there are several limitations, which are illustrated in Figure 2 and discussed below.

Potential compatibility problems between contaminants and inorganic S/S reagents arise when the contaminants include phenols, halides, cyanides, or sulfates (2). Salts have been shown to cause swelling and cracking in solidified matrices (3). The presence of oil and grease may negatively affect the rate of curing depending on their concentrations in the contaminated soil. Compatibility tests between the reagent and contaminants should be performed to determine potential effects on S/S product structural integrity and the leaching of contaminants out of the treated matrix.

Although S/S techniques (ex situ and in situ) have been employed in the treatment of oily and PCB-contaminated wastes, their use in the treatment of wastes contaminated with other, typically more volatile, organic compounds may be limited. Specific concerns in the application of S/S to these other organics include:

- The organic may act as a solvent for some organic-based S/S reagent systems (3);
- The organics may inhibit the setting or curing reactions necessary to generate an acceptable S/S product (3);
- The potential for generation of air emissions resulting from the volatilization of the organic compounds during reagent and soil mixing and reaction operations; and
- The ability of S/S to reduce the mobility of many organics.

Additional limitations or disadvantages to the use of in situ S/S in remedial activities include: an increase in volume of the

Source	Potential Limitations
Waste characteristics	• Chemical incompatibility between reagent and contaminants • Technology not yet proven effective with a range of organic wastes • Presence of volatile compounds could result in air emissions requiring control • Nonuniform contaminant profiles complicate treatability testing and design
Subsurface characteristics	• Large boulders or debris may preclude the use of available in situ mixing equipment • Soil pH and moisture content may dictate pretreatment and treatment requirements • Inhomogeneities in soil type complicate treatability testing and design
Surface characteristics	• Potential site impact of waste volume increase due to treatment • Application of technology requires considerable site access
Climate	• Potential detrimental effect on product due to wet dry and freeze thaw cycling • High and low temperatures (>150 F, <40 F) may affect curing and settling processes
Product management	• Leaving product in place will require increased assurance (i.e., site monitoring) that environmental protection is maintained over the long term • Few established methods to ensure product quality over the long term • Relative newness of technology in remedial applications does not provide for data reflecting long-term performance of the technology

Figure 2. Potential Limitations of In Situ S/S

treated matrix due to the addition of large quantities of reagents and difficulties in assessing and maintaining quality assurance during subsurface reagent delivery and mixing operations (see "Quality Assurance Requirements").

In situ S/S vendors may employ proprietary chemicals or reagent systems. It is difficult for Navy personnel to write specifications for the testing and implementation of remedial actions involving the use of proprietary materials. The Navy discourages the use of proprietary reagents unless their chemical composition is known. It should be stressed to the vendor that the Navy will keep the identity of the proprietary reagent confidential. But, since the Navy is responsible for the long-term liability of the site, it must know what chemicals are to be monitored in the soil and groundwater. Breakdown products of the reagent must also be considered.

One of the primary concerns with the use of in situ S/S is the determination and assurance that effective treatment has taken place. Measures of short-term and long-term effectiveness are difficult since the treated materials remain in place in the subsurface. There are currently no reliable methods to allow for a thorough determination of effectiveness.

Many of the potential limitations may be addressed by conducting treatability and pilot tests prior to design and implementation of the remedial action (see "Design Criteria"). Many of these tests may provide for an assessment of short-term effectiveness, but do not necessarily address long-term effectiveness.

Considerable up-front work needs to be completed prior to design and implementation of in situ S/S techniques. Among the required efforts are:

- Regulatory coordination;
- Conduct of treatability study (see "Design Criteria"); and
- Pilot and/or demonstration testing.

The extent of the actual up-front requirements will be site-specific, but they have the potential to significantly increase both the cost and the time required for the total remedial activity.

Interface with Other Technologies

To ensure the permanence of in situ S/S as a remedial solution, the technology may be used in conjunction with other control methods and technologies. At a minimum, due to the decreased permeability of the treated soil matrix, run-off control at the site may be required. In addition, the use of surface infiltration barriers or caps over the treated wastes may be required to provide for:

- Maintenance of proper levels of moisture in the treated matrix to maintain maximum integrity;
- Protection of the treated wastes from the freeze/thaw cycle; and
- Minimization of rain infiltrating into and through the treated matrix.

Subsurface barriers such as slurry walls or geomembranes may be used to surround the treated site to protect the treated matrix from water infiltration as well as to provide additional long-term protection against the contamination of groundwater.

Design Criteria

Few specific design criteria exist for the implementation of in situ S/S in all situations. Rather, these design criteria are developed throughout the remedial response. A typical pathway required to implement an in situ S/S technology to meet remedial requirements is shown in Figure 3.

Figure 3 and the the following discussion relates to a typical remedial response—site-specific requirements will dictate the exact pathway to be taken in any given situation. It is important to emphasize that regulatory coordination must be maintained throughout the entire process.

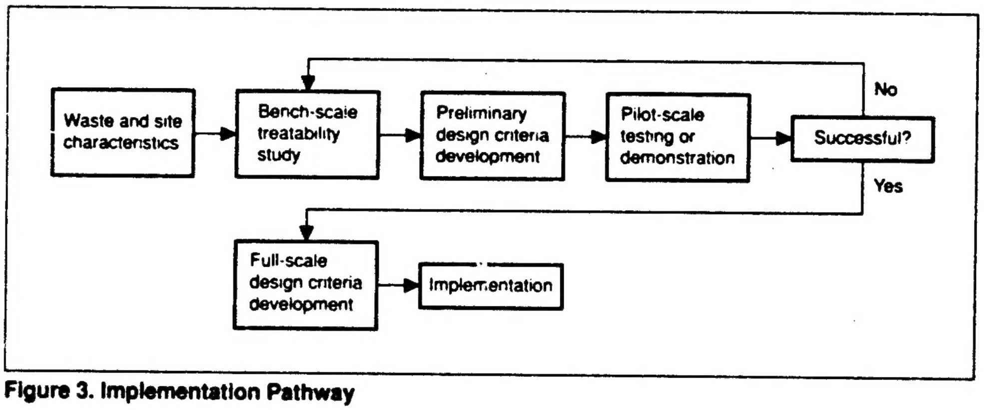

Figure 3. Implementation Pathway

Waste and site characterization will typically entail activities including:

- Sampling;
- Chemical analyses;
- Identification of regulated contaminants;
- Waste volume determination; and
- Physical and geohydrological assessments.

A treatability study will be performed in order to:

- Assess the site-specific feasibility of in situ S/S;
- Select appropriate reagent (binder) systems;
- Optimize process parameters; and
- Provide a basis for pilot-scale design.

Treatability studies will normally include the following activities:

- Process and reagent (binder) screening (literature review);
- Laboratory screening/ bench-scale testing;
- Process and binder selection; and
- Performance optimization.

Based on the results of the treatability study, pilot testing may be performed. As shown in Figure 3, the results of pilot testing may indicate a requirement to repeat some or all of the activities of the treatability study.

If pilot testing is successful, design criteria may be developed for full-scale implementation. At a minimum, the design criteria will reflect elements including:

- Reagent selection;
- Reagent to waste ratio;
- Soil pretreatment requirements (i.e., watering, dewatering, pH adjustment);
- Methods to be employed for reagent addition and optimum mixing;
- Required curing conditions;
- Methods to assess technology performance (leaching potential and durability);
- Requirements for protection of the treated material from wet/dry and freeze/thaw cycles; and
- Long-term monitoring requirements.

Field Implementation Considerations

Because in situ S/S is employed without the excavation of contaminated soil or the placement of treatment materials, field construction activities may be simpler than those associated with ex situ treatment techniques.

Typical S/S construction activities include:

- Mobilization and site preparation;
- Chemical reagent storage and handling;
- Addition of reagent to contaminated soil;
- Mixing of reagent and soil; and
- Cleanup and closure.

Mobilization will include equipment selection based on the methods selected for reagent addition and mixing as well as the breadth and depth of contamination. Area mixing techniques performed by traditional earth-moving equipment such as backhoes, bulldozers, clamshells, and draglines may be used depending on the size and profile of the contaminated site.

Although feasible, mechanical area mixing is unlikely to result in adequate mixing (3). To address mixing concerns, specialized equipment has been developed to provide for subsurface injection of reagent and in-place mixing. These techniques are described below.

It is important that adequate on-site reagent storage is established to prevent delays in remedial operations. Reagent storage is also critical to provide for protection of the reagent from the environment. Handling of the reagent is an important consideration—equipment must be selected to effectively transport dry bulk solids and liquids as necessary. The use of control equipment is critical to provide for the proper metering of reagent to maintain the desired reagent to waste ratio.

The addition of reagent to the contaminated soil may be accomplished by using pneumatic pumps or dump trucks to distribute the reagent over the contaminated surface or by subsurface injection of the additives.

The most critical aspect of the in situ S/S process is the thorough and uniform mixing of the reagent with the soil. Recently, specialized equipment has been developed that provides for reagent addition and mixing.

One in situ S/S process employs a combination of an auger and caisson as shown in Figure 4. In this process, the reagent is fed into the hollow stem of the auger and injected into the waste as the auger is rotated within the caisson into and out of the soil. As the auger rotates, it provides for mixing of the reagent and soil. As shown in Figure 4, columns of treated material are generated. Positioning for the treatment of additional columns is planned so that the columns overlap, providing for complete site coverage (3). The developer reports that the equipment may be used to a depth of 150 feet (2). Use of this addition and mixing process was recently demonstrated as part of the SITE program.

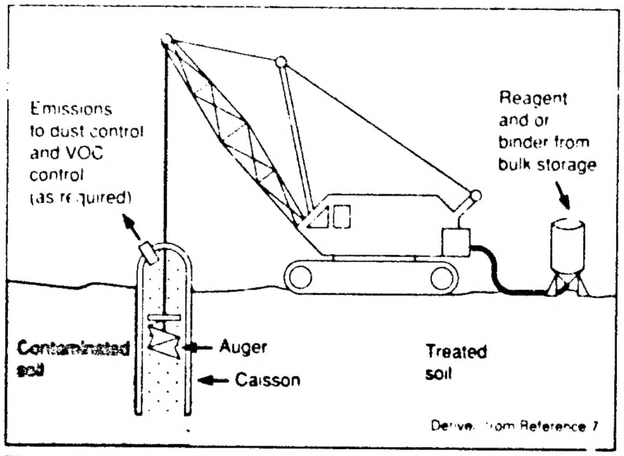

Figure 4. Auger/Caisson In Situ S/S System

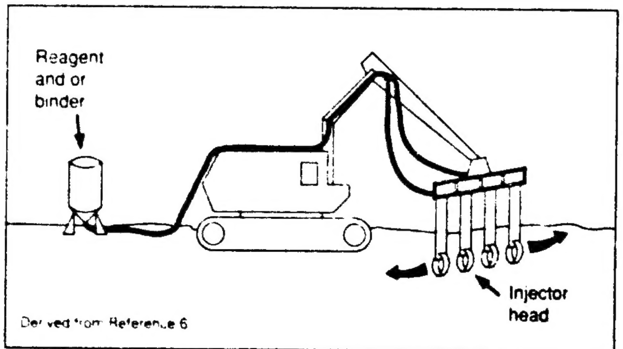

Figure 5. Injector Head In Situ S/S System

A second reagent addition/mixing system, shown in Figure 5, makes use of an injector head installed on a backhoe. The reagent is typically fed pneumatically from a truck to the injector head where it is injected into the soil. Mixing occurs by the back and forth movement of the injector head and the force of the pneumatic delivery (3). Treatment depths are typically less than 18 feet.

Additional demonstrated injector/backhoe techniques include the use of injection and mixing systems employing pneumatic injector tubes outfitted with impellers and augers for mixing (3).

Reagent addition and mixing operations may require the use of air emission control techniques such as dust collectors for particulates and activated carbon adsorption for volatile organic compounds (VOCs). Additional particulate emission control techniques that may be employed include (4):

- Minimization of material handling;
- Erection of portable wind screens;
- Installation of portable surface covers during periods of inactivity; and
- Construction of temporary enclosures.

The most significant post-treatment site cleanup requirements include equipment and personnel decontamination. Specific site closure requirements may vary but will generally include capping of the site with a low permeability (hydraulic conductivity of 10 ˙ or less) layer. In addition, regulatory requirements will dictate activities to monitor air, surface water, and/or groundwater.

Quality Assurance Requirements

Strict quality assurance (QA) measures are critical throughout the process application and most important during addition and subsequent mixing of the reagent with the waste. In ex situ applications, qualitative and quantitative QA measurements can be made during rehandling of the treated waste prior to final disposal. Unfortunately, the ability to make these measurements is difficult during in situ processing. For this reason, QA during in situ S/S applications is best achieved by maintaining a significant level of experienced, on-site inspection and supervision (3).

With respect to on-site activities involved in in situ S/S actions, there are several parameters that can be assessed to maintain QA. For example, parameters that have been shown to affect the mixing of the reagent and waste and thus the ultimate product quality include (5):

- Viscosity of the reagent;
- Permeability of the contaminated soils;
- Porosity of the contaminated soils;
- Distribution of the wastes; and
- Rate of reactions between reagents and wastes.

A number of tests may be used to assess the potential effectiveness of in situ S/S as well as assess the quality of the product. Examples of representative tests, their purpose, and available or applicable criteria are presented in Figure 6. These tests may be conducted during feasibility studies and may be employed with pre- and post-treatment wastes.

The tests listed in Figure 6 represent a small fraction of tests that may be used for in situ S/S applications. The large number of applicable tests presents a significant problem to the remedial designer or engineer. There is no established technical guidance for which tests are best employed in a given situation.

This problem is particularly pronounced in the selection of appropriate leaching tests to determine the degree of contaminant mobility in the untreated and treated materials. Ideally, the leaching procedure selected would simulate field conditions. Realistically, no single procedure can duplicate all poten-

Test	Criteria	Purpose
Particle size analysis	Well graded 74 m-0.25 in	Determine gradation of untreated soil
Atterberg liquid and plastic limits	Liquid limits 40-55% water, plastic limits 20-50% water	Measure of untreated soil compressibility and strength as a function of water content
Moisture content	Application-specific	Determine need for watering or dewatering untreated soil
Density	Application-specific	Measure of porosity of untreated and treated materials; used to indicate volume increase as a result of treatment
Permeability	$<10^{-5}$ cm/s	Measure of resistance of material to passage of water
Unconfined compressive strength	50 psi	Measure of durability of treated material
Freezing/thawing and washing/drying	<15% weight loss (suggested)	Measure of durability of treated material
Leaching tests	Application-specific	Measure of mobility of contaminant
Microstructural analysis	Application-specific	Determination of grading of untreated soil; determination of degree and uniformity of mixing in treated material

Figure 6. Examples of Quality Assurance Measurements

tial field conditions. Therefore, the selection of leaching procedures to be used in treatability studies and in the field is a critical element in QA.

Similar problems are encountered in the selection of physical property tests to establish a measure of durability of the treated materials.

Additional information regarding applicable tests and their selection is provided in references 3 and 6.

Residuals Generated

One of the attractive features of in situ S/S processes is that residuals are minimized due to the absence of excavation and transportation of contaminated materials and placement of treated product.

The primary residuals of concern that may be generated during in situ S/S include:

- Emission control residues such as particulates from dust collectors or spent activated carbon used in volatile organic control;
- Liquid and solid residues resulting from personnel and equipment decontamination and cleaning; and
- Excess reagent.

Special attention must be paid to the management and disposal of the emission control and cleanup/decontamination residues either or both of which may be classified as hazardous.

Regulatory Issues

Regulatory issues affecting the remediation of contaminated sites continue to evolve. A majority of remedial activities may fall under requirements mandated in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Superfund Amendments and Reauthorization Act (SARA) of 1986.

Of importance to the use of S/S technologies is the requirement under SARA that remedial actions meet all "applicable or relevant and appropriate requirements" (ARARs) established from federal and more stringent state standards.

When initiating a remedial action, it is necessary to first identify all of the ARARs that may apply. Among the requirements that may apply are those specified in the Resource Conservation and Recovery Act (RCRA), the Clean Water Act (CWA), and the Clean Air Act (CAA). In addition, if the site contains PCBs or PCB-contaminated materials, the Toxic Substances Control Act (TSCA) will apply.

If in situ S/S processes are used to treat hazardous wastes, certain aspects of RCRA may be applicable. Of the requirements, the most likely to be ARARs for in situ S/S are those that are related to the long-term management of the treated site including requirements governing closure and post-closure (2). Potential impacts may include requirements for capping and post-closure care including long-term groundwater monitoring.

One important exception to RCRA requirements may be the apparent exclusion of in situ treatment actions from Land Disposal Restrictions (LDR). *Since in situ treatment does not involve the "placement" of treated wastes, LDR may not apply.*

Specific cleanup standards may affect the selection of S/S. Cleanup standards may be established in terms of permissible levels of specific contaminants in leachate generated from a standard test such as the EPA Toxicity Characteristic Leaching Procedure (TCLP). Cleanup standards may also be expressed in terms of the concentration of the contaminant of interest in the treated waste (not the leachate). This latter standard may present difficulties with respect to S/S due to the fact that generally the S/S technology does not destroy the contaminant but merely places it in a less mobile form.

The most important regulatory consideration in the selection and use of in situ S/S in any situation is the requirement that effective communication between the regulatory agencies and the party responsible for the remediation be maintained. This communication will influence the selection of the remedial technology as well as its design and implementation.

Feasibility Study (FS) Criteria Ranking

The use of in situ S/S processes has been rated by remedial action and engineering experts with respect to the relative ability of the process to meet performance and regulatory criteria relevant to FS evaluations. The results of this rating are provided in Figure 7.

There are a number of caveats to the presentation of this rating. One of the concerns is that since a majority of S/S processes do not result in contaminant destruction, it is difficult to compare these processes to those technologies that do destroy the contaminant.

In addition, a rating for long-term effectiveness must be subjective due to the absence of data reflecting this effectiveness.

Implementability of the in situ S/S process is negatively affected by the substantial requirements for treatability studies and tests prior to implementation.

Consideration of the relative costs of employing in situ S/S must also be addressed. Due to the considerable efforts that may be required prior to actual implementation of in situ S/S, preliminary costs may be high. Although the actual costs to conduct in situ S/S in the field may be relatively low, total costs associated with the remedial action may be high (see "Key Cost Factors").

Criteria	Ranking
Effect of reducing the overall threat to human health and the environment	
Vulnerability to ARARs (Applicable or Relevant and Appropriate Requirements)	
Long-term effectiveness (see text)	
Effectiveness at reducing toxicity, mobility, and volume	
Short-term effectiveness	
Implementability	
Transportability	
Up-front cost	
Field cost (full-scale)	
Readiness of acceptance by the state and community	

Favorable ◄——► Unfavorable

Figure 7. Performance Criteria Rating

Key Cost Factors

Costs associated with in situ S/S remedial activities include the cost of:

- Tasks required prior to field implementation including site characterization, treatability study, and pilot-scale testing or demonstration; and
- Actual field implementation including site preparation, raw materials, treatment activities, and site cleanup and closure.

Total costs associated with in situ S/S remedial applications are very dependent on site-specific conditions and requirements. Issues that have been identified as having the greatest potential for affecting the total cost include:

- Waste characteristics (physical and chemical) and quantity;
- Site hydrogeology;
- Requirements for pretreatment;
- Specific treatment requirements (i.e., cleanup standards and time to complete treatment);

- Selection of reagents and additives to be employed;
- Health and safety considerations;
- Requirements for emission control;
- Regulatory requirements; and
- Site layout

Ranges of costs (1991 dollars) that may be encountered are:

- *Costs prior to actual treatment:* $50,000 to $1,000,000 (total, assumed to be independent of volume to be treated); and
- *Costs of treatment:* $50 to $250 per cubic yard

Points to Remember

The following points are important to consider in the selection, design, or implementation of in situ S/S to treat contaminated soil. These points are not intended to be all-inclusive, but represent critical elements as noted by those experienced in the implementation of in situ S/S technologies.

- In situ S/S does not necessarily represent a permanent remedial solution.
- The treatability study may be the most significant undertaking of the remedial process (see "Design Criteria").
- The complete remedial activity may involve the preparation of several specifications for contracting to address treatability study, pilot testing, and implementation phases.
- Little is known about the long-term effectiveness of in situ S/S.
- Special consideration must be taken in the selection of QA tests, particularly leaching and durability tests.
- Adequate site investigation and characterization is required to identify hydrogeological, physical, and chemical conditions or constraints that affect the application of in situ S/S.
- Ongoing operations at the site must be considered in planning the application.
- If dust control is required during operations, an on-site source of water may be needed.
- The future use of the site must be considered in designing the in situ S/S treatment process. In some cases, a significant increase in volume may result from treatment, thereby affecting the local terrain. In addition, future use requirements may dictate the design and construction of caps over the treated materials.
- The potential for climate effects resulting in frequent wet/dry and freeze/thaw cycling must be considered in feasibility assessments.
- The use of proprietary reagents or binders may be a concern with respect to preparing contracting specifications as well as potential long-term liability.
- The maintenance of effective communications with the appropriate regulatory agencies is important in the selection and implementation of in situ S/S. This is especially critical due to the uncertainties involved in assuring short- and long-term treatment effectiveness and long-term monitoring requirements.

Application Examples

Examples of recent (within the last 5 years) applications of in situ S/S for the treatment of contaminated soils and sludges are provided in Figure 8. These examples were selected to provide a representation of the variety of site or contaminant conditions that may be encountered.

The first two examples represent applications in which in situ S/S was employed to treat industrial sludges containing a variety of contaminants, including metals. Although these examples do not address contaminated soil treatment, they

Site	Volume	Contaminant	Reagent	Special Considerations	Ref.
Refinery	100,000 yd^3	oil, Pb, Cr, As	cement, kiln dust	Full-scale treatment of contaminated sludge	5
Electroplating facility	16,000 yd^3	Cu, Cr, Ni	Portland cement	Full-scale treatment of contaminated sludge	5
Electric service shop	7,500 yd^3	PCB, Cr, Cu, Pb, Zn	proprietary reagent/ pozzolan	SITE demonstration. Treated contaminated soil to depths of 25 to 53 feet.	2
Oil refinery	100,000 yd^3	petroleum hydrocarbons	cement	Subsurface application of dry reagent to contaminated soil. Site enclosed by slurry wall and capped with clay.	7

Figure 8. Application Examples

are representative of large scale in situ S/S applications with a variety of contaminants.

The third example reflects the conduct of a SITE demonstration test employing in situ S/S to treat actual soils contaminated with metals and PCBs. In this EPA evaluated demonstration, a proprietary reagent was combined with sodium silicate and added by injection to the contaminated soil. Mixing took place by the movement of an auger within a column during injection. A complete demonstration description and presentation of results is provided in Reference 2. Preliminary results indicate that the technology could be practically employed by this method and apparent immobilization of metal and non-volatile organic contaminants may have occurred. One year after the demonstration, the treated product was analyzed and indicated that the permeability of the treated matrix decreased significantly over time (8).

An in situ S/S application to treat a large volume of soil contaminated with petroleum hydrocarbons used cement to generate a strong, solid structure that physically trapped the contaminants. This application represents an integrated treatment system that employed in situ S/S and surface and subsurface barriers (see Figure 1).

References and Sources of Additional Information

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